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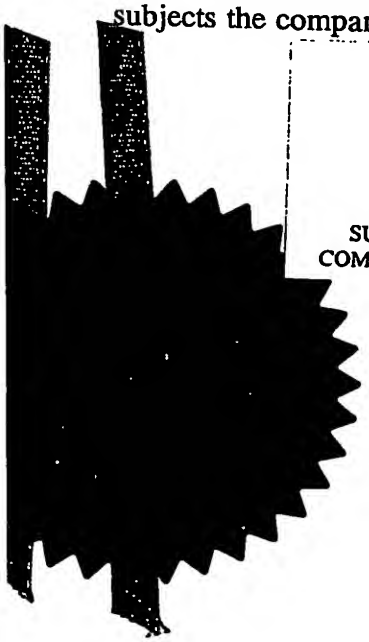

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Dated 15 August 2003

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22OCT02 E757803-1 D10119
P01/7700 0.00-0224585.0

1. Your reference — **P/2030.GB/CJW**

2. Patent application number *(The Patent Office will fill in this part)* — 0224585.0 — 22 OCT 2002

3. Full name, address and postcode of the applicant or of each applicant *(underline all surnames)*

Xsil Technology Limited
Unit 3, Trinity Enterprise Centre
Pearse Street
Dublin 2
Ireland

08687197001

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation — **Ireland**

4. Title of the invention — **LASER MACHINING**

5. Name of your agent *(if you have one)* — **Wildman, Harrold, Allen & Dixon**

"Address for service" in the United Kingdom to which all correspondence should be sent

(including the postcode)

11th Floor, Tower 3,
Clements Inn,
London,
WC2A 2AZ
United Kingdom

Patents ADP number *(if you know it)* — **08187346001**

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* each application number

Country	Priority Application Number *(if you know it)*	Date of Filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body
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Yes

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Continuation sheets of this form	
Description	6
Claim*(s)*	4
Abstract	1 DMC
Drawings*(s)*	1+1

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Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	1 ✓
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Wildman Harrold Date **22 Oct 2002**
WILDMAN, HARROLD, ALLEN & DIXON

12. Name and daytime telephone number of person to contact in the United Kingdom **Clifford J. Want** **020 7831 0009**

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LASER MACHINING

The present invention relates to laser machining, particularly of bodies containing at least a significant proportion of silicon.

Silicon reacts vigorously with all the halogens to form silicon tetrahalides. Thus, silicon reacts with fluorine, F_2, chlorine, Cl_2, bromine, Br_2, and iodine, I_2, to form respectively silicon fluoride, SiF_4, silicon chloride, $SiCl_4$, silicon bromide, $SiBr_4$, and silicon iodide, SiI_4. The reaction with fluorine takes place at room temperature but the other reactions require heating to over 300 °C.

$$Si + F_2 = SiF_4 \text{ (gas)}$$

$$Si + Cl_2 = SiCl_4 \text{ (gas)}$$

It is also known from US5266532A and US5322988A that the presence of halocarbons accelerates the ablation of silicon. An example of a halocarbon-silicon reaction is,

$$Si + CF_4 = SiF_4 \text{ (gas)} + C \text{ (solid)}$$

The reaction between halocarbons and silicon is not spontaneous. The reaction occurs only at energies above the melting threshold of silicon, and therefore is very localized and suitable for one-step silicon micro-machining applications such as wafer dicing, vias and surface patterning.

It is an object of the present invention to provide enhanced machining of silicon compared with that of the prior art.

According to a first aspect of the invention, there is provided a method for machining a silicon body with a laser beam, comprising the steps of: providing a halocarbon environment in at least a machining location of the silicon body; directing the laser beam at the machining location of the silicon body in the halocarbon environment; locally heating the halocarbon with the laser beam in the vicinity of the machining

location of the silicon body sufficiently to cause a chemical reaction between the silicon body and the halocarbon at the machining location; and machining the silicon body at the machining location with the laser beam thereby causing the chemical reaction to take place at the machining location.

Conveniently, the step of directing the laser beam comprises directing an UV wavelength laser beam.

Alternatively, the step of directing the laser beam comprises directing a green visible light wavelength laser beam.

Conveniently, the step of providing a halocarbon environment comprises providing an environmental chamber for containing the halocarbon.

Preferably, the step of providing a halocarbon environment comprises providing a refrigerated liquid halocarbon.

Advantageously, the step of providing a refrigerated liquid halocarbon comprises controlling the temperature of the refrigerated liquid halocarbon before, during and after machining.

Alternatively, the step of providing a halocarbon environment comprises providing aerosol nozzle means for delivering the halocarbon to at least the machining location.

Conveniently, the step of providing a halocarbon environment comprises providing a halocarbon containing a halogen selected from the group of fluorine, chlorine, bromine and iodine.

Advantageously, the step of machining the silicon body comprises controlling the temperature of the silicon body substantially to prevent thermal damage to the silicon body by controlling thermal loading of the silicon body.

According to a second aspect of the invention, there is provided a laser machining apparatus comprising: a laser; means for directing a laser beam from the laser onto a machining location; and means for providing a controlled halocarbon environment around at least the machining location.

Conveniently, the means for providing a controlled halocarbon environment comprises environmental chamber means.

Preferably, the environmental chamber means comprises bath means for a refrigerated liquid halocarbon.

Conveniently, the environmental chamber means comprises an inlet port and an outlet port for liquid halocarbon, and a gas vent.

Preferably, the environmental chamber means comprises a silica glass window for entry of the laser beam into the environmental chamber means.

Advantageously, the silica glass window is anti-reflection coated.

Preferably, the laser machining system further comprises refrigeration means for providing a refrigerated liquid halocarbon to the environmental chamber means.

Advantageously, the refrigeration means is arranged for controlling a temperature of the liquid halocarbon before, during and after machining.

Alternatively, the means for providing a controlled halocarbon environment comprises aerosol nozzle means for delivering the halocarbon to at least the machining location.

Conveniently, the laser emits at ultraviolet wavelengths.

Alternatively, the laser emits at green visible light wavelengths.

Preferably, the laser machining system further comprises temperature control means for controlling a temperature of a body to be machined at the machining location,

arranged substantially to prevent thermal damage of the body by controlling thermal loading of the body.

Conveniently, the laser machining system further comprises telecentric lens means for directing the laser beam, wherein a flow of the refrigerated halocarbon substantially fills a field of view of the telecentric lens means.

The invention will be more clearly understood from the following description of some embodiments thereof, given by way of example only with reference to the accompanying drawings in which:-

Fig. 1 is a perspective schematic view of a laser machining apparatus according to the invention; and

Fig. 2 is a plan view of the apparatus of Fig. 1.

In the figures, like reference numerals represent like parts.

Referring to Figs. 1 and 2, a laser machining apparatus 1 comprises a stainless steel enclosure 2 having a liquid inlet 3, a liquid outlet 4, and a gas vent 5. An optical system 10 is mounted above the enclosure. An enclosed liquid bath is completed by an anti-reflection coated silica glass window 15 to allow access of a UV laser beam to a silicon wafer W in the bath. Alternatively, a laser emitting green visible light may be used.

In use, the wafer W is placed in the enclosure 2 and a refrigerated liquid halocarbon such as tetrafluoroethane is pumped into the bath via the inlet 3. Alternatively, some other liquid halocarbon, producing a halogen such as fluorine, chlorine, bromine or iodine, may be used. The inlet 3 and the outlet 4 are in a refrigeration circuit so that the liquid temperature is maintained at or below the gas transition temperature of the particular halocarbon. The bath is at least partially filled with the liquid.

The temperature of the substrate W to be machined and the temperature of the active fluid may be controlled before, during and after machining in order to improve the efficiency of machining and also to improve the quality of machining.

The temperature of the wafer substrate W in an ambient environment may be varied in order to permit greater thermal control during laser machining by reducing thermal loading in the substrate and thus preventing thermal damage to the substrate.

The UV beam 6 is directed at the desired machining site on the wafer W for the desired machining operation. Locally, at the machining site, the laser beam heats the silicon so that the immediately surrounding liquid is both heated above the gas transition temperature, and the temperatures of both the silicon and the gas are sufficient for a reaction to take place. In this situation most of the by-products are gases and are vented away through the gas outlet 5. Those which are solid particles are dispersed in the liquid and are not re-deposited onto the wafer surface.

The advantage of this system is that the system permits distribution of the liquid halocarbon over a relatively large area of the surface of the substrate to be machined, thus permitting efficient and uniform machining. For laser machining of via structures, dice lanes or scribe lanes in a wafer substrate using a galvanometer based scanner, telecentric lens and linear XY motorised table, the flow of refrigerant halocarbon can be optimised so as to fill completely the field of view of the telecentric lens (for example this may typically be 50 mm x 50 mm in size). All features to be machined within the field of view can be machined very efficiently as refrigerated halocarbon is present across the entire field of view and the XY stage does not need to be moved. Also, all features within the field of view are machined uniformly (i.e. they are of similar depth and quality) due to the even distribution of refrigerant halocarbon within the field of view.

Thus, it will be appreciated that the invention provides for very efficient and high quality laser machining.

The invention is not limited to the embodiments described but may be varied in construction and detail. For example, the liquid may comprise mixtures of halocarbons and other liquids. Also, the environmental chamber may be partly filled with a refrigerated halocarbon liquid and the remainder filled with a gas. Also not only UV, but instead green lasers can be used. Also there can be more than one inlet, to allow the insertion of other liquids or gases into the environmental chamber.

Although the invention has been described for machining a silicon body, the invention has application at least for machining any body containing a significant proportion of silicon.

Claims

1. A method for machining a silicon body with a laser beam, comprising the steps of:

   a. providing a halocarbon environment in at least a machining location of the silicon body;

   b. directing the laser beam at the machining location of the silicon body in the halocarbon environment;

   c. locally heating the halocarbon with the laser beam in the vicinity of the machining location of the silicon body sufficiently to cause a chemical reaction between the silicon body and the halocarbon at the machining location; and

   d. machining the silicon body at the machining location with the laser beam thereby causing the chemical reaction to take place at the machining location.

2. A method as claimed in claim 1, wherein the step of directing the laser beam comprises directing an UV wavelength laser beam.

3. A method as claimed in claim 1, wherein the step of directing the laser beam comprises directing a green visible light wavelength laser beam.

4. A method as claimed in any of claims 1 to 3, wherein the step of providing a halocarbon environment comprises providing an environmental chamber for containing the halocarbon.

5. A method as claimed in any preceding claim, wherein the step of providing a halocarbon environment comprises providing a refrigerated liquid halocarbon.

6. A method as claimed in claim 5, wherein the step of providing a refrigerated liquid halocarbon comprises controlling a temperature of the refrigerated liquid halocarbon before, during and after machining.

7. A method as claimed in any of claims 1 to 3, wherein the step of providing a halocarbon environment comprises providing aerosol nozzle means for delivering the halocarbon to at least the machining location.

8. A method as claimed in any preceding claim, wherein the step of providing a halocarbon environment comprises providing a halocarbon containing a halogen selected from the group of fluorine, chlorine, bromine and iodine.

9. A method as claimed in any of the preceding claims, wherein the step of machining the silicon body comprises controlling a temperature of the silicon body substantially to prevent thermal damage to the silicon body by controlling thermal loading of the silicon body.

10. A laser machining apparatus comprising: a laser; means for directing a laser beam from the laser onto a machining location; and means for providing a controlled halocarbon environment around at least the machining location.

11. A laser machining apparatus as claimed in claimed in claim 10, wherein the means for providing a controlled halocarbon environment comprises environmental chamber means.

12. A laser machining apparatus as claimed in claim 11, wherein the environmental chamber means comprises bath means for a refrigerated liquid halocarbon.

13. A laser machining apparatus as claimed in claims 11 or 12, wherein the environmental chamber means comprises an inlet port and an outlet port for the liquid halocarbon, and a gas vent.

14. A laser machining apparatus as claimed in any of claims 11 to 13, wherein the environmental chamber means comprises a silica glass window for entry of the laser beam into the environmental chamber means.

15. A laser machining apparatus as claimed in claim 14, wherein the silica glass window is anti-reflection coated.

16. A laser machining system as claimed in any of claims 11 to 15, comprising refrigeration means for providing a refrigerated liquid halocarbon to the environmental chamber means.

17. A laser machining system as claimed in claim 16, wherein the refrigeration means is arranged for controlling a temperature of the liquid halocarbon before, during and after machining.

18. A laser machining apparatus as claimed in claim 10, wherein the means for providing a controlled halocarbon environment comprises aerosol nozzle means for delivering the halocarbon at least to the machining location.

19. A laser machining apparatus as claimed in any of claims 10 to 18, wherein the laser emits at ultraviolet wavelengths.

20. A laser machining apparatus, as claimed in any of claims 10 to 18, wherein the laser emits at green visible light wavelengths.

21. A laser machining system as claimed in any of claims 10 to 20 comprising temperature control means for controlling a temperature of a body to be machined at the machining location, arranged substantially to prevent thermal damage of the body by controlling thermal loading of the body.

22. A laser machining system as claimed in any of claims 10 to 21, further comprising a telecentric lens means for directing the laser beam, wherein a flow

of the refrigerated halocarbon substantially fills a field of view of the telecentric lens means.

23. A method substantially as described herein with reference to and as shown in the accompanying Figures.

24. A laser machining system substantially as described herein with reference to and as shown in the accompanying Figures.

ABSTRACT

A silicon body W is machined with a UV or green laser beam 6 in a refrigerated halocarbon environment. Local heating with the laser beam of the halocarbon in the vicinity of a machining location is sufficient to cause a chemical reaction between the silicon body and the halocarbon which accelerates machining, enhances machining quality and reduces laser machining generated debris.

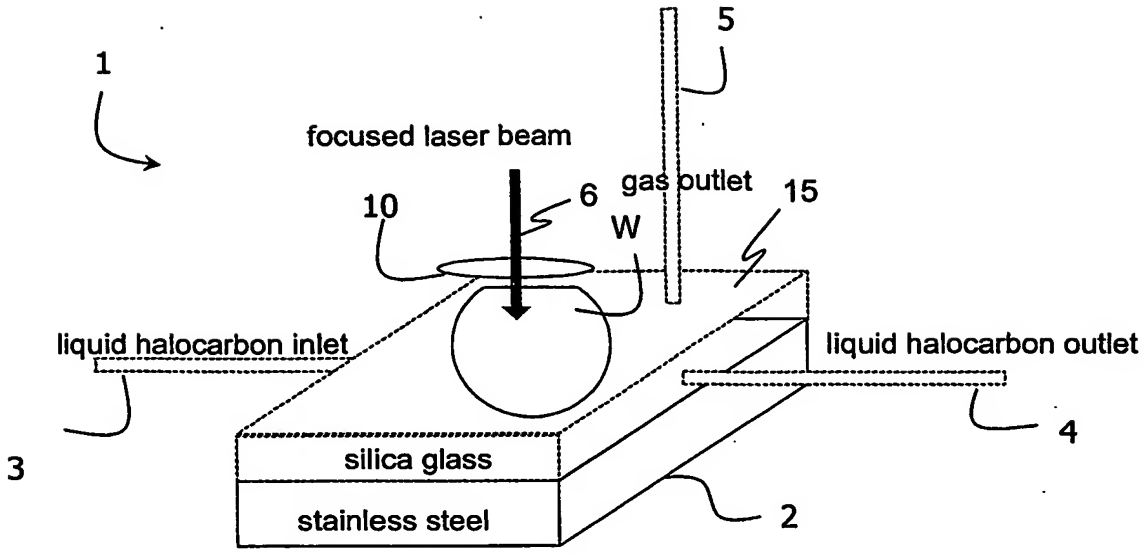
1
5
focused laser beam
6
gas outlet
15
10
W
liquid halocarbon inlet
liquid halocarbon outlet
3
4
silica glass
stainless steel
2

Fig. 1

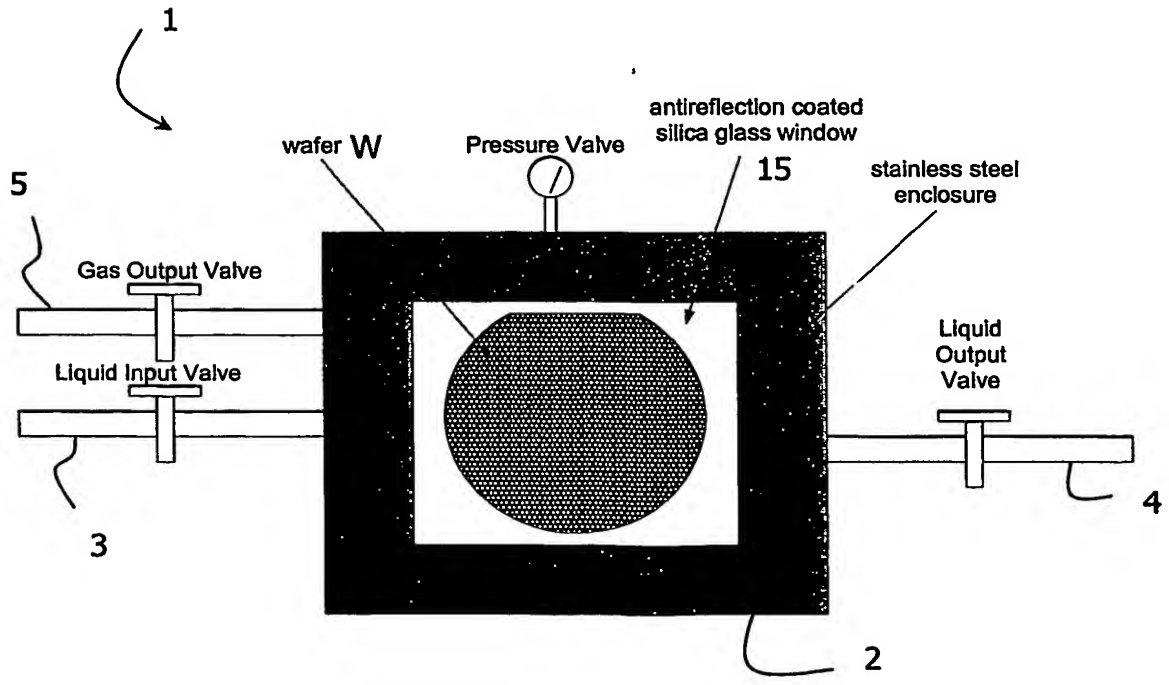
1
wafer W
Pressure Valve
antireflection coated
silica glass window
15
stainless steel
enclosure
5
Gas Output Valve
Liquid Input Valve
Liquid
Output
Valve
3
4
2

Fig. 2